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MODELING THE SATURATION LEVEL OF A HUMAN RADAR OPERATOR

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The United States Air Force is building a mathematical model of the air battle and needs, as an input, a model of the saturation level of the ground-based enemy radar operator. Saturation level can be loosely defined as the number of targets that the human operator can effectively manage. The concept of an ideal operator is introduced to allow the precise definition of saturation level. An ideal operator is defined as an operator who can perform a certain amount of work per unit time perfectly. The amount of work that the ideal operator can perform is termed the operator's saturation level. The

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human operator is then modeled as an ideal operator who makes random errors. The human operator's saturation level is then estimated from a series of measurements as a function of the human's maximum time-between-errors.

An experiment which was conducted to measure saturation level is described in detail and the results are presented. The resulting data is then analyzed using the Kolmogorov-Smirnov and Likelihood Ratio tests. The results of analysis suggest that the random variable, saturation level, is governed by the distribution of the largest extreme value. In addition, it is shown that the human operator's saturation level changes as the rate at which targets are introduced varies.

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MODELING THE SATURATION
LEVEL OF A HUMAN
RADAR OPERATOR

THESIS

Presented to the Faculty of the School of Engineering

The Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Dahl B. Metters

Captain USAF

Graduate Electrical Engineering

December 1974

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Preface

The work which follows is the result of a large number of hours of research, computer programming, program debugging, experimenting, analyzing, and planning. This project has given me a new respect for those who do research; especially those who do research and make it appear to be easy.

If I were to choose one facet of this thesis project which is particularly significant, I would pick the development of the concept of the ideal operator to assist in precisely defining human saturation level. To my knowledge, human saturation level has never been modeled before and introducing the idea of the ideal operator greatly simplifies the problem. I believe that with suitable modification, the concept of the ideal operator could be used to assist in modeling the reliability of electrical and mechanical parts under severe stress.

There is no way that I can adequately express my gratitude to my thesis advisor, Professor T. L. Regulinski, for his invaluable help and, more significantly, his encouragement during the dark hours of this project.

During the 2-1/2 years that I have been studying engineering, my wife has typed reports, punched cards, run errands, operated my simulator (Operator #17), analyzed experimental results, typed this thesis, and, most importantly, been my inspiration. Thank you, Erin.

Dahl B. Metters

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Abstract

The United States Air Force is building a mathematical model of the air battle and needs, as an input, a model of the saturation level of the ground-based enemy radar operator. Saturation level can be loosely defined as the number of targets that the human operator can effectively manage. The concept of an ideal operator is introduced to allow the precise definition of saturation level. An ideal operator is defined as an operator who can perform a certain amount of work per unit time perfectly. The amount of work that the ideal operator can perform is termed the operator's saturation level. The human operator is then modeled as an ideal operator who makes random errors. The human operator's saturation level is then estimated from a series of measurements as a function of the human's maximum time-between-errors.

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MODELING THE SATURATION LEVEL OF A HUMAN RADAR OPERATOR

I. Introduction

Background

The United States Air Force is in the process of creating a new mathematical model of the air battle. Experience in the air war over North Vietnam has proven current models inaccurate in a modern electronic warfare environment. Among the inputs that the Air Staff requires for this model is the saturation level of the ground radar operator (Ref 2 & Ref 3). Saturation level is usually defined as the maximum number of targets which can be managed effectively at one time by the human operator. Previous models have generally considered the human operator to be saturated at some arbitrary number of targets or stress level. No tested or generally accepted model of the operator's performance presently exists.

While numerous studies of radar operator performance have been made, none have specifically attempted to quantify saturation level. A simulation by Kidd (Ref 13) indicated that experienced air traffic controllers could efficiently maintain 4 to 8 target tracks with no loss in efficiency. The study of Ref 13 is not directly applicable to the problem at hand since a major task in a military radar system, detection of new targets, was not required. Thomas (Ref 22:68) reported that operators graduating from military operator schools must be able to monitor about 10 aircraft

concurrently and also vector two intercepts. Again, no detection tasks were required.

The relation between workload and operator performance was studied by Huntley (Ref 10:65) in 1972. The result of his study indicated how people react to an overload of work, but no attempt was made to define or measure saturation level. A study which included both detection and tracking tasks was performed by Mills in 1973 (Ref 16:348). Operator performance as a function of five system parameters was measured. One of the parameters was rate of target introduction. This study is of limited applicability because the experimental subjects tended to drop the track maintenance task and, again, measurement of saturation level was not a goal of the study.

Objectives

The primary objective of this thesis is to formulate a model of the human radar operator's saturation level. To do this, tasks which constitute the performance repertoire of the operator will be delineated, a precise definition of saturation level will be given, an experiment capable of generating the appropriate data will be designed and conducted, and the probabilistic model will be formulated from the resulting data.

Approach

An analysis of the modeling problem is given in Chapter II. The basic tasks required of the human radar operator are examined and factors which influence the operator's performance are specified and discussed. The concept of an ideal operator is then introduced. The human operator is

modeled as an extension of the ideal operator in order to define saturation level precisely.

Chapter III is a description of the experiment that was performed to generate the data necessary for the model formulation. The equipment used is described and the detailed experimental procedure is given.

The method used to determine the underlying probability density function of the random variable, saturation level, is presented in Chapter IV. The details of isolating the density function and estimating the parameters are explained.

The specific results of analysis are detailed in Chapter V and Chapter VI contains the conclusions and recommendations.

II. Analysis of the Problem

Tasks

In any early warning or area defense radar system, two major tasks must be performed by a radar operator in conjunction with the radar system being used (Ref 14:4). The tasks are:

Detection (Track Initiation). Detection of targets is a task in which radar returns are correlated and then classified as a target by the operator.

Tracking (Track Maintenance). Tracking of targets is the process of noting subsequent returns after a target is detected and plotting the course of the target in some manner.

Variables

The saturation level of the human operator, the random variable under study, is influenced by many factors. These variables may be characterized as being related to the radar system in use, to the operator, or to the scenario.

Radar System Variables. Any characteristic of the radar system in use that could possibly influence the human operator's performance is a radar system variable. These are:

1. Mechanical Aids. Mechanical operator aids can greatly assist (or hinder) the human in keeping track of targets.

2. Required Operator Response. According to Wargo (Ref 23:221), the response that the man-machine system required of an operator will greatly influence the operator's capability. If an operator must make a

complex response to indicate a detected target or to indicate tracking, there will be less time for these basic tasks than there would be if the required response were simpler.

3. Other system Factors. Many other radar system factors could influence the operator's performance. Studies have shown that such things as ambient noise can significantly alter target detection performance (Ref 24:245). Other variables are the type of radar display, the area assigned to each operator for surveillance, and the physical surroundings of the operator.

Scenario Variables. Scenario variables are those variables which depend upon the exact nature of the enemy force and its deployment. Variables of this type are:

1. Confusion Factors. Confusion factors are any devices that could be used by the enemy force to attempt to reduce the effectiveness of the total man-machine radar system. Electronic countermeasures (ECM) and evasive maneuvers are examples. Any successful attempts at confusion would lower the operator's saturation level.

2. Signal Predictability. If the operator can predict where new targets will appear and the path they will take after appearance, they will be easier to track.

3. Geometric Deployment of the Force. The rate of appearance and the paths of the targets upon the radar display could alter the operator's performance. In an experiment performed by Bell and Symington (Ref 4:65), it was found that performance deteriorated with increasing target density. Mills (Ref 16:348) asserts that the velocity of the targets on the display affects performance.

4. Other Scenario Factors. The results of a study conducted by Bernstein (Ref 5:1) indicates that the performance of subjects detecting targets on a cathode-ray tube is sensitive to other variables of the scenario such as variations in target type, target-to-background contrast, and image rate of motion.

Operator Variables. Some attributes of the individual operator which could affect his saturation level are:

1. Training. The extent of the operator's training will have a major impact on his performance. The operator who has just begun his training cannot be expected to do as well as one who has had many years of experience on the job.

2. Other Psychophysiological Factors. Various other psychophysiological factors could have major impact upon the human radar operator's performance. Teichner (Ref 21:181) showed that detection performance is seriously degraded as the length of the watch is increased. Any other influences which reduce the operator's sense of well-being or state of mind, such as fatigue or tension, could also tend to decrease his saturation level.

The Ideal Operator

In order to precisely define human saturation level, the concept of the ideal operator will first be considered. An ideal operator is defined as one who can perfectly manage a certain number of actions per unit time. The number of actions that the ideal operator can manage per unit time is termed the operator's saturation level. If an ideal operator, with saturation level s actions per unit time, is presented with a

workload of less than s actions per unit time, no errors will be made. If the operator is presented with a workload greater than s, s actions per unit time will be managed perfectly. It follows then, that the average rate at which the perfect operator will make errors, e, is:

$$e = w - s \qquad \text{if } w > s$$

or

$$0 \qquad \text{if } w \leq s$$

where w is the average workload required to be done, measured in actions per unit time. The ideal operator's average time-to-error (time between errors), t, is then:

$$t = \frac{1}{e} = \frac{1}{w-s} \qquad \text{for } w > s \tag{1}$$

The average time-to-error of the ideal operator is depicted in Fig. 1 as a function of average workload.

The Human Operator

The concept of the ideal operator is used to model the human operator by thinking of the human as an ideal operator who makes additional mistakes in some random manner. To be able to take this approach, the time period of observation must be short enough so that the effects discussed in Chapter II as operator variables do not change the performance level of the operator. Thus, the human operator's error rate, E, will be:

$$E = e + X \tag{2}$$

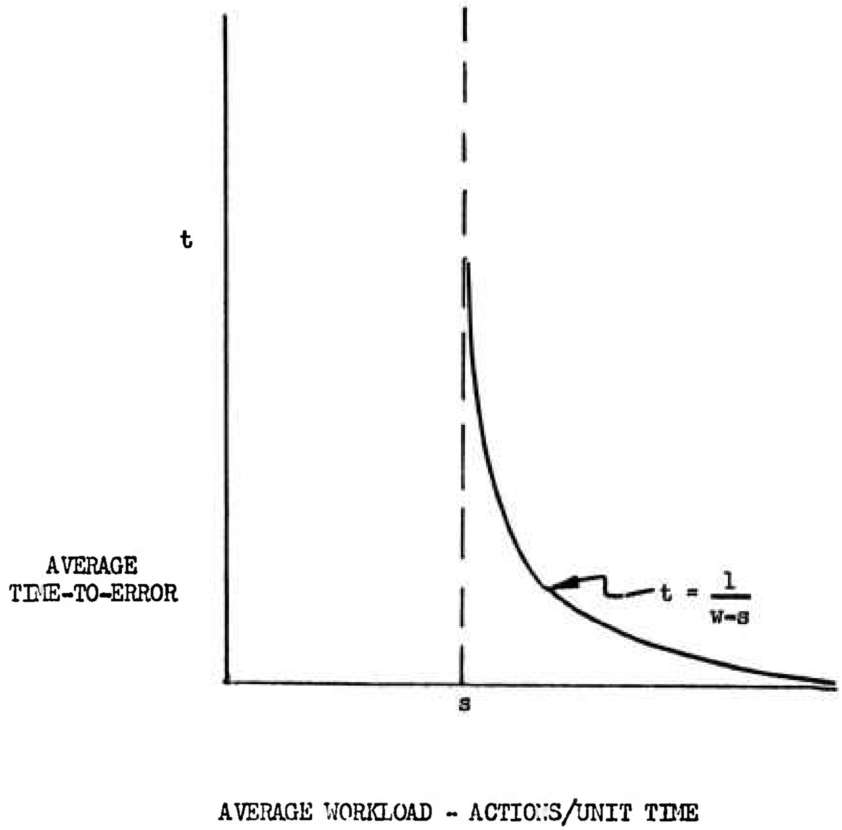

Fig. 1. Average Time-to-error of Ideal Operator

where e is the error rate which is induced by the ideal operator portion of the model and X is an additional random error rate. From the initial conception of the model, X is a random variable which is strictly positive.

The saturation level of a human operator, s, measured in actions per unit time is, therefore, defined to be:

$$S = \omega - e \qquad \text{if} \quad \omega > e$$

where w is the human's average workload in required actions per unit time and e is the error rate attributable to the ideal operator portion of the human's performance.

The human's time-to-error, T, is

$$T = \frac{1}{e + X} \tag{3}$$

It is clear from (1) and (3) that

$$T \leq t$$

If many observations of a human operator are made at a constant workload, w_0, a group of sample times-to-error, T_i (i=1,...,n), will be observed. An estimate of t, $\hat{t}$, can be made:

$$\hat{t} = MAX\,(T_i)$$

By using $\hat{t}$, an estimate of the operator's saturation level, $\hat{s}$, is made as follows:

$$\hat{S} = \omega_0 - \frac{1}{\hat{t}}$$

It is apparent that:

$$\hat{s} = \mathrm{MAX}(s_i) \tag{4}$$

with

$$s_i = \omega - \frac{1}{T_i}$$

will yield the same estimate of s.

If the above method of estimating the human's saturation level, s, is carried out at many different levels of workload, one may have more confidence that the operator was tested at a level greater than saturation.

Reaction Time Measurements

A conceivable alternative to the above method of estimating saturation level is by means of reaction time measurements. It seems reasonable to assume that if a human operator requires an average of t_r seconds to respond to a stimulus, the human, acting at that rate, can only manage $1/t_r$ responses per second.

A secondary goal of this project will be to attempt to model $1/t_r$ as a function of workload. If this approach to the modeling problem is feasible, it may be possible to isolate the individual effects of the detection and tracking task workloads on saturation level.

Modeling Saturation Level

After a method of measuring saturation level has been obtained, it is possible to model the saturation level of a group of operators.

The random variable is s, saturation level, and f(w) is the probability density function governing s. Thus -

$$P \left\{ \text{human operator is saturated with workload } w_0 \text{ to } w \mid \text{stress} \right\}$$
$$= \int_0^{\omega} f(\omega)\, d\omega$$

Using the saturation level data gathered by experiment, the underlying density function governing the random variable, s, is isolated using the method described in Chapter IV.

III. Experimental Procedure

An experiment was conducted to gather data with which to model the saturation level of the human radar operator. The experimental procedure called for subjects to perform the functions of a radar operator in a controlled simulation with a workload sufficient to produce errors induced by saturation. Data was recorded so that the times at which errors were made, as well as reaction times could be determined.

In order that the observed differences in performance accurately reflected basic differences in saturation levels, all variables listed in Chapter II that could be controlled, were held constant. Specifically, to minimize error:

1. Individual simulation tests were short (ten minutes) in order to avoid the effects of fatigue.

2. The tasks performed were as simple as possible to reduce the influence of learning.

3. Each subject was given identical training and instructions.

The Simulator

The equipment used was the Saturation Countermeasures Simulator (SATSIM) located at the Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio. The simulator is described more completely elsewhere (Ref 16: 32-37), but is basically capable of displaying a multitude of targets and ECM effects. A simplified block diagram of the SATSIM is given in Fig. 2.

The PDP-8 computer reads target information from the digital magnetic tape and passes it to the digital-to-analog converter. Details con-

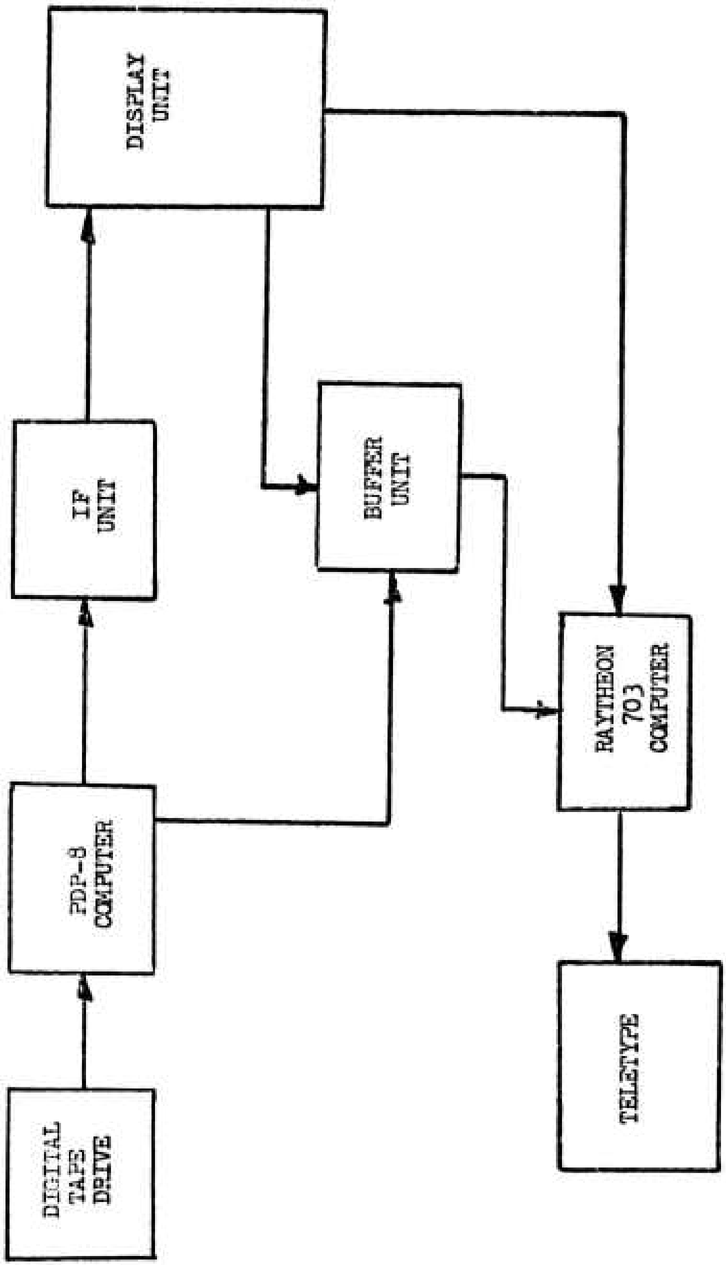

Fig. 2. Simplified Block Diagram of the SATSIM

cerning the digital magnetic tape format are contained in Appendix B. The digital-to-analog converter has four independent analog output channels which are connected to the four input channels of the Intermediate Frequency (IF) Unit. The controls of the IF Unit allow any or all of the four signal channels to be applied to the PPI display Unit.

The primary method of recording data reflecting the reactions of experimental subjects is by means of the Raytheon 703 Computer. Whenever the output pushbutton, located at the PPI device, is activated, the Raytheon 703 computer prints information contained in the Buffer Unit. This information consists of the number of seconds since the current simulation run began, the position of the operator controlled azimuth cursor in degrees, as well as information concerning IF Unit switch settings.

Fig. 3 is a photograph of the input portion of the SATSIM. The

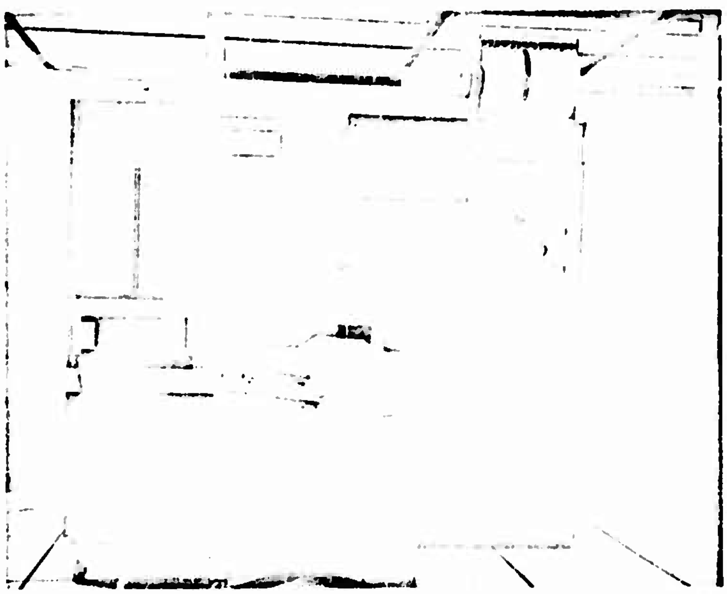

Fig. 3. The Input Portion of the SATSIM

PDP-8, the digital-to-analog converter, and the magnetic tape drive are pictured. Fig. 4 shows the Raytheon 703 and the IF Unit.

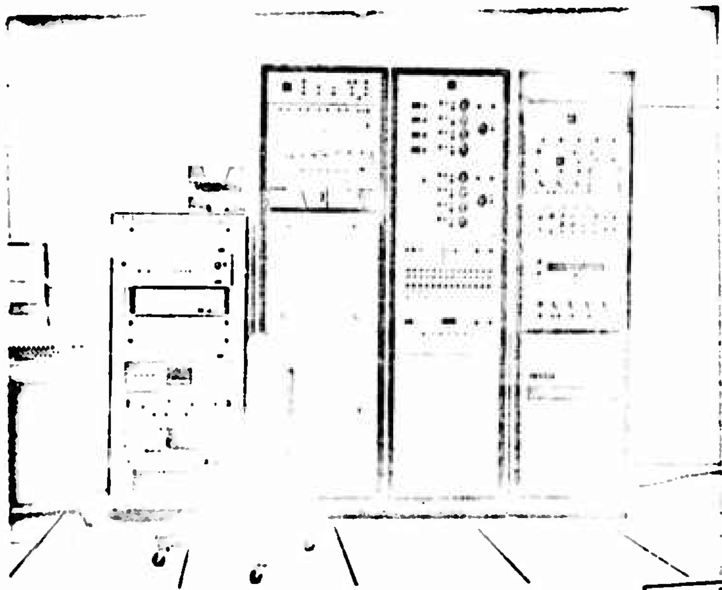

Fig. 4. The Raytheon 703 and the IF Unit

A portable cassette tape recorder was also used to record verbal comments which experimental subjects were required to make during their tests (see Tasks, below).

Experimental Display

The display unit used in this study is pictured in Fig. 5. It is a standard UPA-35 PPI indicator modified to accept inputs from the SATSIM. The radar simulated for this experiment had a pulse repetition frequency of 400 pulses per second and an antenna scan rate of six revolutions per

minute. The two controls of most concern to the subjects, the azimuth cursor control and the output pushbutton, are located on the lower right-hand portion of the display unit. The operator pictured in Fig. 6 is shown operating the azimuth cursor control. The pushbutton is located six inches to the right of this control.

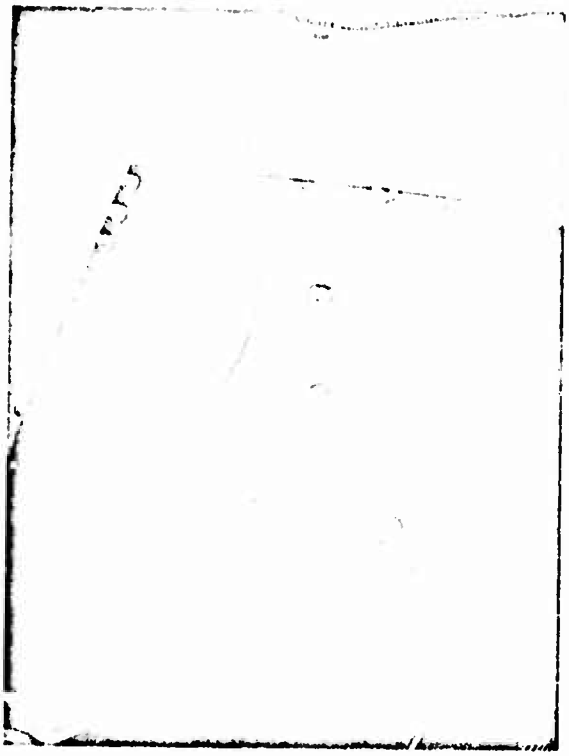

Fig. 5. The Display Unit

Fig. 6. An Operator Using the UPA-35 PPI

The display unit was set to display a simulated area of 100 miles in radius with 20-mile range markers for this experiment.

Tasks

Each subject was required to monitor a surveillance area consisting of approximately one-quarter of the display area and also to perform the functions of target detection and tracking. The area monitored was a ninety-degree quadrant extending from 315 to 45 degrees in azimuth and from the eighty-mile range marker in to the center of the cathode ray tube. The detection task consisted of:

1. Noticing that a new target was present and assigning the target a number. Integers beginning at one were used; each new target was given the next consecutive number.

2. Moving the azimuth cursor so that it covered the new target.

3. Activating the pushbutton and verbally announcing the target number into the microphone of the cassette tape recorder.

The tracking task required the same response whenever an already detected target crossed one of the 20-mile range markers. The number announced was the original number assigned to the target.

Each simulation test began with no targets on the display and targets were programmed to appear at random times throughout the test. Targets were also programmed to appear at a random azimuth in the ninety-degree sector and at a random range between 60 and 80 miles to prevent subjects from predicting where they would appear. The number of targets programmed to appear on each of the simulation runs was determined during preliminary trials with subjects not used in the final experiment.

Subjects

Twenty adult volunteers were used in the experiment. Of these, sixteen were male students of the Air Force Institute of Technology and four were female volunteers. None of the subjects had previous experience as a radar operator.

Procedure

Each subject completed one session with the simulator per day on four consecutive days. The simulation tests and instructions were identical for all subjects.

The first day was entirely devoted to training. The subject was told that the purpose of the experiment was to measure the saturation level of human radar operators. After a brief description of the equipment, the subject was seated at the display unit and shown the azimuth cursor control, the output pushbutton, and the various intensity controls. Then a demonstration was given of tracking targets on the display using a grease pencil. Finally, the subject was told to read the instructions which detail the tasks to be done by the operator. A copy of these instructions appear as Appendix A. After the instructions had been read, a ten-minute training simulation run was begun. During the training run, the subject was closely observed to confirm that required responses were understood and were being performed.

The second day of testing was devoted to practice. The operator was again closely watched during a rerun of the same training run that was presented on the first day. Then after a short rest, the subject was told to begin Run 1, his first 'real' run. By, the end of this ten-minute run, the scope contained eleven targets which was approximately twice the number in the first run. The subject was alone in the testing room and the cassette tape recorder was set to record for the first time. This simulation run was scored so that the subject would know how well he did, but to minimize errors induced by learning, the results were not used for final data analysis.

The third day of testing consisted of subjecting the operator to two ten-minute simulation runs, Run 2 and Run 3. The activity on these runs was slightly higher than that used on Run 1, 13 targets on Run 2 and 15

targets on Run 3. Before taking the subject into the testing room, the results of Run 1 were discussed. As before, between the two runs, the subject was given a short rest period.

On the fourth day of testing, the subject was shown the results of the third day. This last run, Run 4, consisted of one simulation run with sixteen targets.

Equipment Problems Encountered

During the testing of subjects, several problems with the simulator equipment became apparent. It is not believed that these difficulties had any significant influence upon the final results of the experiment. The problems are recorded here for completeness.

Occasionally during the early part of the testing program, the targets being displayed would suddenly appear to shift clockwise by 22-1/2 degrees. This seemed to indicate that a block of data on the tape had not been read. Upon closer investigation, the pinch roller on the magnetic tape transport was found to be worn. Since a replacement was not available, a temporary solution was found. The roller was cleaned, buffed with an emory cloth, and installed in a reversed position. The skipping stopped except on the tape that held the last simulation run, Run 5. Since time was short, this run was deleted from the testing program.

Another problem involved the printed output of the Raytheon 703 computer. Occasionally, grossly incorrect times were printed even though the other information was printed correctly. The cause of this difficulty was never determined. Because it was possible to measure the correct times from the tapes of the portable cassette tape recorder, this was not considered to be a serious problem.

A problem occurred that involved the appearance of the targets upon the PPI display. At apparently random times throughout a simulation run, a 'ghost' image would appear in the immediate vicinity of a real, displayed target. The ghost image would always appear closer to the center of the display and approximately 4 miles from the real target. The ghost was at the same azimuth and about one-fifth the intensity of the real target. The problem was definitely in the SATSIM equipment since the ghosts appeared at different times and places each time a given simulation was run. All test subjects were shown examples of the ghosts and told to ignore them and concentrate upon the real targets. Based upon observations of the subjects during training, it is conjectured that the ghosts had little effect upon the experimental results.

Scoring of Test Results

The individual simulation runs were scored as follows:

1. The tape recording of the ten-minute run was played and the numbers that the operator called out were noted on the output sheet from the Raytheon 703 computer. Because the computer frequently made errors in printing out the time, as the tape was played, all times were checked for accuracy and corrected where necessary. This was possible since activating the pushbutton produced a distinct click which could be heard on the tape recording. It was possible to measure time with a wrist watch since the time was printed to the nearest second.

2. The output sheet was then studied to discover any errors made by the test subject. Errors were indicated when a target was not detected, when a target crossed a range marker unnoticed, or when the wrong target number was used.

3. By using the times at which errors were made, the estimate of the operator's saturation level, $\hat{s}$, was made using (4).

4. The response times of the operator for detection tasks and tracking tasks were calculated for the portions of the run that were not in error.

IV. Analysis of Test Data

The experiment described in Chapter III produces two groups of data, estimated saturation levels and measured response times. These data will be used to formulate the models discussed in Chapter II. The method used to isolate the underlying density function governing the random variables under investigation, saturation level and response time, is patterned after work done by Regulinski and Askren (Ref 18:407-415). Steps in their procedure include:

1. Parameters are estimated for each of the probability distributions that are being considered.

2. The Kolmogorov-Smirnov test is conducted for each of the distributions.

3. The likelihood ratio test is performed to identify which of the distributions passed by the Kolmogorov-Smirnov test is most likely to be the underlying density function governing the generated data.

Distributions and Estimation of Parameters

The distributions tested are listed in Table I. Both the probability density function (PDF) and the cumulative distribution function (CDF) are listed. Table II is a listing of the formulas used for estimating the parameters of the probability distributions. These estimates were all taken from Ref 19 except for the estimates for the Pareto and Laplace distributions which were taken from Ref 11 and Ref 12, respectively.

Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov test is a powerful nonparametric tool which can be used to test the hypothesis that a group of data comes from a population with a particular cumulative distribution function (Ref 15:68-78). The method is based upon a comparison of the cumulative step-function of the random sample and the theoretical cumulative distribution function. The maximum difference between the two functions is found. Based upon the number of sample points and the desired significance of the test, the table of Ref 15 can be consulted to determine if the hypothesis that the stated distribution function applies, is accepted.

The Kolmogorov-Smirnov test is conducted at the .2 significance level using Massey's critical values (Ref 15:68-78). This is a fairly conservative step as several distributions may be accepted, but the problem of low discrimination will be corrected in the next step.

Likelihood Ratio Test

The likelihood ratio test (Ref 9:213) is performed for all distributions that do not fail the Kolmogorov-Smirnov test. For each distribution under consideration, a likelihood function represents the likelihood that the given sample could occur given the distribution function. If $\theta_1, \theta_2, \ldots, \theta_k$ are the parameters of the probability density function $f(x;\theta_1 \ldots \theta_k)$, then the likelihood function, $L(X,\theta)$, is:

$$L(X,\theta) = \prod_{i=1}^{n} f(X_i; \theta_1 \ldots \theta_k)$$

for the set of n samples X. If there are 2 distributions under consideration, the ratio of the likelihood functions,

$$\frac{L_1}{L_2} = \frac{\Pi f_1(X, \theta_1)}{\Pi f_2(X, \theta_2)}$$

will determine which is the most likely underlying distribution function. According to the rationale discussed in Ref 18, the threshold value of this test is unity. Thus, if L_1/L_2 is greater than one, f_1 is more likely, otherwise, f_2 is the better choice.

It is evident that if j distributions are under consideration, $f_1, f_2, \ldots, f_j$, the best choice corresponds to the largest L. If the logarithms of the L's are compared, the largest logarithm corresponds to the most likely function.

Computer Program

The above procedure was translated into a FORTRAN computer program to automate data analysis. A flow chart of the program is given in Fig. 7.

Up to 1000 data points are read into the computer and then are sorted into an array of increasing values. Using the array, four values that are used frequently throughout the program are calculated and stored in a common storage area. These values are:

1. SUM1 = ΣX_i
2. SUM2 = ΣX_i^2
3. SUM3 = $\Sigma \ln(X_i)$
4. SUM4 = $\Sigma [\ln(X_i)]^2$

At this point, one subroutine is called for each of the distributions being considered as candidates for the model. In each of the subroutines,

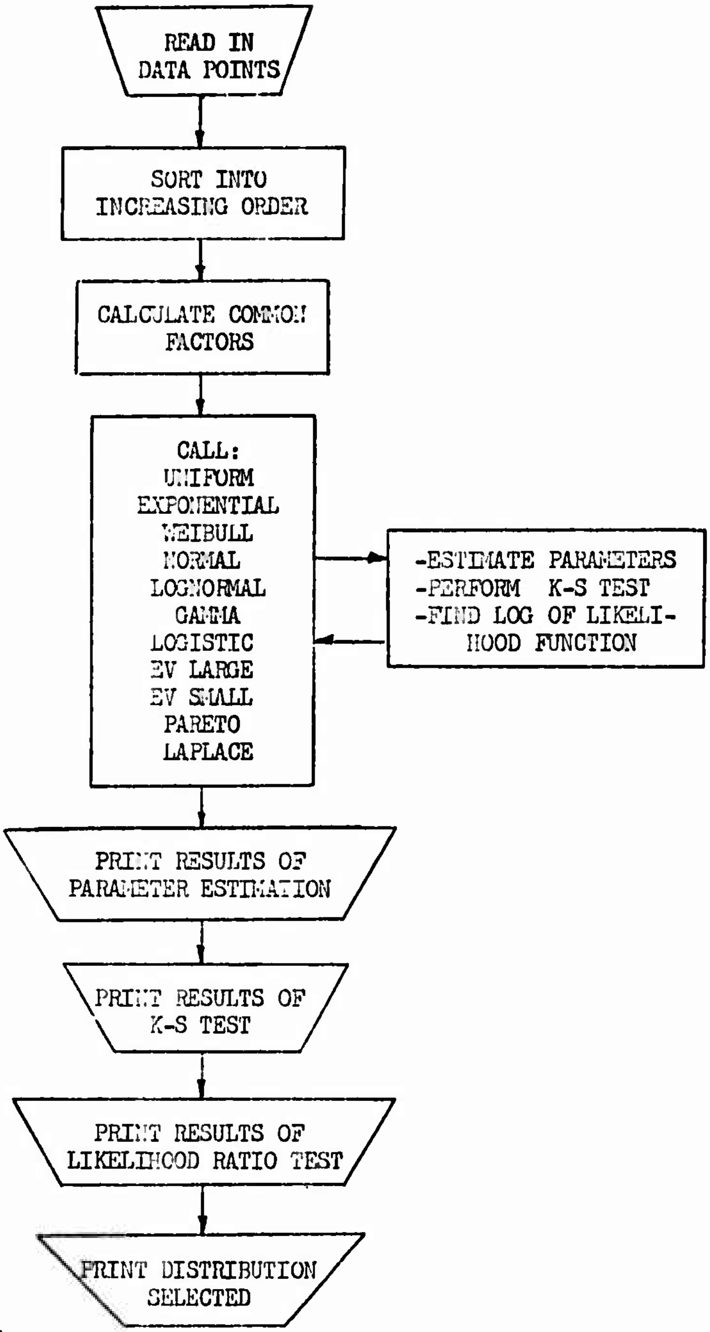

Fig. 7. Flow Chart of Data Analysis Program

the parameters of the particular distribution are estimated. Then using these parameters, the maximum difference between the cumulative sample step-function and the theoretical cumulative distribution function is determined for the Kolmogorov-Smirnov test. A decision is then made as to whether the test has been passed. The next step is to calculate the value of the logarithm of the likelihood function. The results are passed back to the main program.

The remainder of the program prints the results of the tests and the final decision. A complete listing of the computer program is contained in Appendix D.

TABLE I

Distribution Functions

DISTRIBUTION	PROBABILITY DENSITY FUNCTION	CUMULATIVE DISTRIBUTION FUNCTION
Uniform	$f(x) = \frac{1}{\beta - \alpha}$ for $\alpha \leq x \leq \beta$	$F(x) = \frac{x - \alpha}{\beta - \alpha}$ for $\alpha - x - \beta$
Exponential	$f(x) = \frac{1}{\mu} \exp[-(x - \theta)/\mu]$	$F(x) = 1 - \exp[-(x - \theta)/\mu]$
Weibull	$f(x) = \frac{\beta}{\alpha}\left(\frac{x}{\alpha}\right)^{\beta - 1} \exp[-\left(\frac{x}{\alpha}\right)^{\beta}]$	$F(x) = 1 - \exp[-\frac{x}{\alpha}]$
Normal	$f(x) = \frac{1}{\sqrt{2\pi}\cdot\sigma} \exp[-\frac{1}{2}\left(\frac{x - \mu}{\sigma}\right)^2]$	$F(x) = \int_{-\infty}^{x} f(t)\, dt$
Log-Normal	$f(x) = \frac{1}{\sqrt{2\pi}\, x\cdot\sigma} \exp[-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2]$	$F(x) = \int_{-\infty}^{x} f(t)\, dt$
Gamma	$f(x) = \frac{x^{\alpha - 1}}{\Gamma(\alpha)\cdot\beta^{\alpha}} \exp[-\frac{x}{\beta}]$	$F(x) = \int_{0}^{x} f(t)\, dt$
Logistic	$f(x) = \frac{\pi}{\sigma\sqrt{3}} \exp[-\frac{\pi}{\sqrt{3}}\left(\frac{x - \mu}{\sigma}\right)]\{1 + \exp[-\frac{\pi}{\sqrt{3}}\left(\frac{x - \mu}{\sigma}\right)]\}^{-2}$	$F(x) = \{1 + \exp[-\frac{\pi}{\sqrt{3}}\left(\frac{x - \mu}{\sigma}\right)]\}^{-1}$
Extreme Value-Smallest	$f(x) = \frac{1}{\beta} \exp\{\frac{x - \mu}{\beta} - \exp[\frac{x - \mu}{\beta}]\}$	$F(x) = 1 - \exp\{-\exp[\frac{x - \mu}{\beta}]\}$
Extreme Value-Largest	$f(x) = \frac{1}{\beta} \exp\{-\frac{x - \mu}{\beta} - \exp[-\frac{x - \mu}{\beta}]\}$	$F(x) = \exp\{-\exp -[\frac{x - \mu}{\beta}]\}$
Pareto	$f(x) = \frac{a\, k^{a}}{x^{a + 1}}$ for $a > 0 \quad x \geq k > 0$	$F(x) = 1 - (k/x)^{a}$
Laplace	$f(x) = \frac{1}{2\cdot\phi} \exp[-\lvert x - \theta \rvert/\phi]$	$F(x) = \frac{1}{2} \exp - (\theta - x)/\phi \quad x \leq \theta$ $= 1 - \frac{1}{2} \exp - (x - \theta)/\phi \quad x \geq \theta$

TABLE II

Parameter Estimation Formulas

DISTRIBUTION	
Uniform	$\alpha = \mathrm{Min}\{x_i;\ i = 1,\ldots,n\}$ $\beta = \mathrm{Max}\{x_i;\ i = 1,\ldots,n\}$
Exponential	$\theta = \mathrm{Min}\{x_i;\ i = 1,\ldots,n\}$ $\mu = \frac{\Sigma x_i}{n} - \theta$
Weibull	$\beta = \left[\frac{6}{\pi^2}\left(\frac{\Sigma(\ln x_i)^2}{n-1} - \frac{(\Sigma \ln x_i)^2}{n(n-1)}\right)\right]^{-\frac{1}{2}}$ $\alpha = \exp \frac{\Sigma \ln x_i}{n} + \frac{.57}{\beta}$
Normal	$\mu = \frac{\Sigma x_i}{n}$ $\sigma = \left[\frac{\Sigma x_i^2}{n} - \frac{\Sigma x_i}{n}^2\right]^{\frac{1}{2}}$
Log-Normal	$\mu = \frac{\Sigma \ln x_i}{n}$ $\sigma = \left[\frac{n\Sigma(\ln x_i)^2 - (\Sigma \ln x_i)^2}{n(n-1)}\right]^{\frac{1}{2}}$
Gamma	$\alpha = \frac{1}{4} y^{-1}(1 + \sqrt{1 + 4y/3})$ $\beta = \frac{\Sigma x_i}{n\alpha}$ $y = \ln \bar{x} - \frac{\Sigma \ln x_i}{n}$
Logistic	$\mu = \frac{\Sigma x_i}{n}$ $\sigma = \left[\frac{\Sigma x_i^2}{n} - \left(\frac{\Sigma x_i}{n}\right)^2\right]^{\frac{1}{2}}$
Extreme Value Smallest	$\mu = \frac{\Sigma x_i}{n} + .5772\beta$ $\beta = \frac{\sqrt{6}}{\pi}\left[\frac{\Sigma x_i^2}{n} - \left(\frac{\Sigma x_i}{n}\right)^2\right]^{\frac{1}{2}}$
Extreme Value Largest	$\mu = \frac{\Sigma x_i}{n} - .5772\beta$ $\beta = \frac{\sqrt{6}}{}\left[\frac{\Sigma x_i^2}{n} - \left(\frac{\Sigma x_i}{n}\right)^2\right]^{\frac{1}{2}}$
Pareto	$k = \mathrm{Min}\{x_i;\ i = 1,\ldots,n\}$ $a = \left[\frac{\Sigma \ln x_i}{n} - \ln k\right]^{-1}$
Laplace	$\theta = \mathrm{Median}\ x_i$ $\phi = \frac{\Sigma x_i - n\theta}{n}$

V. Results of Analysis

The experimental data collected using twenty subjects is presented as Appendix E. The results of subjecting these data to the analysis procedures discussed in Chapter IV are given below. The discussion is in two parts, analysis of saturation level data and analysis of reaction time data.

Analysis of Saturation Level Data

The data from Runs 2, 3, and 4 were subjected to the procedure discussed in Chapter II; an estimated saturation level, $\hat{s}$, was calculated for each of the twenty experimental subjects. These saturation levels are listed in Table III. The estimated saturation levels were then used as inputs to the computer program described in Chapter IV to isolate the underlying density function governing the random variable, saturation level.

The distributions accepted by the Kolmogorov-Smirnov test for each run are:

Run 2	Run 3	Run 4
Uniform	Exponential	Weibull
Normal	Extreme Value-Largest	Normal
Log-Normal	Pareto	Log-Normal
Logistic		Logistic
Extreme Value-Largest		Extreme Value-Smallest
		Extreme Value-Largest

TABLE III

Estimated Saturation Levels, $\hat{s}$

SUBJECT	RUN 2	RUN 3	RUN 4
1	.112806	.114247	.122047
2	.099598	.123282	.124751
3	.112806	.095819	.095363
4	.097282	.101656	.108694
5	.098362	.116106	.110267
6	.081190	.101688	.123711
7	.083735	.097161	.118667
8	.097282	.100908	.124751
9	.094116	.112755	.124679
10	.090972	.094310	.113810
11	.099598	.108938	.119725
12	.094116	.1011656	.124679
13	.095057	.116106	.124559
14	.112835	.097660	.123711
15	.099598	.099784	.108694
16	.109176	.096429	.110071
17	.098362	.116106	.110071
18	.089127	.094310	.115431
19	.094524	.101656	.116562
20	.106394	.101656	.124747

NOTE: All saturation levels are measured in actions per second.

The distributions selected from the above results by the likelihood ratio test are:

Data	Distribution Selected	Parameters		Mean	Variance
Run 2	Uniform	α = .08119	β = .1128	.09700	$.8327\times10^{-4}$
Run 3	Exponential	θ = .09431	μ = .01030	.10461	.01105
Run 4	Ext Value - Smallest	β = .005689	μ = .1212	.1179	$.5324\times10^{-4}$

A review of the results of the Kolmogorov-Smirnov test indicates that the only distribution accepted for Runs 2, 3, and 4 was the extreme value-largest. If one probability density function governs the random variable, saturation level, based upon the available evidence, it must be the extreme value-largest density function. Estimated parameters of the function are:

	β	μ	Mean	Variance
Run 2	.006810	.09442	.09835	$.7628\times10^{-4}$
Run 3	.006670	.1008	.1047	$.7319\times10^{-4}$
Run 4	.005689	.1146	.1179	$.5323\times10^{-4}$

To determine whether the parameters of the underlying exteme value-largest density function changed from Run 2 to Run 3 and from Run 3 to Run 4, two tests were made.

Sign Test. The sign test is a simple nonparametric test to determine whether two groups of data can have come from populations governed by the same underlying density function (Ref 9:310). Using the procedures given in Ref 9, it was found that the probability of obtaining two groups of samples from one population as divergent as those for Runs 2 and 3 is .0018. The corresponding probability for Runs 3 and 4 is less than .001.

Monte Carlo Simulation. A Monte Carlo simulation was undertaken to determine whether the differences obtained between the estimated parameters of Runs 2, 3, and 4 were significant. One hundred groups, each containing twenty data points, were generated using the extreme value-largest density function. Parameters were:

$$\beta = .006670 \qquad \mu = .1008$$

The parameters, β and μ, of these groups were then estimated using the formulas of Table II. In approximately 70 percent of the cases the Monte Carlo estimates for β showed more variation than did the estimates for Runs 2, 3, and 4. The Monte Carlo estimates for μ, however, showed less variation in all cases than did the estimates for Runs 2, 3, and 4.

It seems clear that the parameter μ of the extreme value-largest distribution changed significantly from Run 2 to Run 4 while β was constant or nearly so.

Number of Targets at Saturation

The average workload of the operator can be related to the number of targets appearing on the display at any time by considering the random variable representing workload, W, to be a sum:

$$W = \sum_{i=1}^{n} X_i + Y$$

where – X_i represents the tracking workload of the i^{th} target

Y represents the detection workload (all workloads measured in tasks per second)

Then

$$E(W) = nE(X) + E(Y) \qquad \text{(Ref 9:118)}$$

or

$$w = na + b$$

where - w is the average workload measured in actions per second

n is the number of targets on the display

a is the average rate at which tracking actions are to be performed, measured in actions per second per target

b is the average rate at which detection tasks are to be performed, measured in actions per second

Therefore, solving for n:

$$n = \frac{w - b}{a}$$

For this experiment, the constant a is a function of the velocity of the targets and the distance between the range markers. The standard speed for all targets was approximately 500 miles per hour and the range markers were spaced at 20 miles so that one tracking action was required every 140 seconds.

The constant b, the average rate at which detection tasks are to be performed, varied for each of the simulation runs. This constant is found by dividing the total number of targets appearing on a run by the length of the run in seconds.

The parameters, a and b, are thus:

Run	a	b
2	.007143	.021667
3	.007143	.025000
4	.007143	.026667

The number of targets corresponding to the mean saturation levels are:

Run	Mean Number of Targets
2	10.736
3	11.151
4	12.771

Analysis of Reaction Time Data

The reaction times of all operators were separated according to the number of targets on the display when the stimulus was applied and according to whether the task was a detection or a tracking task. The results of computer analysis of the reaction time data is given below for the detection task at various levels of workload.

Number of Targets on Display	Distribution Selected	Parameters		Mean (Sec)	Variance
0	none	-		-	-
1	none	-		-	-
2	Log-Normal	$\mu = 1.421$	$\sigma = .553$	4.83	8.33
3	none	-		-	-
4	none	-		-	-
5	Log-Normal	$\mu = 1.576$	$\sigma = .581$	5.72	13.16
6	none	-		-	-
7	none	-		-	-
8	none	-		-	-
9	Log-Normal	$\mu = 2.001$	$\sigma = 1.004$	12.24	260.86
10	Exponential	$\theta = 1.000$	$\mu = 16.15$	17.15	294.12
11	Weibull	$\beta = 1.642$	$\alpha = 15.29$	13.68	287.63
12	Log-Normal	$\mu = 2.346$	$\sigma = 1.076$	18.63	757.79
13	Log-Normal	$\mu = 2.098$	$\sigma = 1.070$	14.45	447.06
14	Exponential	$\theta = 3.000$	$\mu = 10.79$	13.79	190.16

In the cases where distributions other than the log-normal were selected, the log-normal was also accepted by the Kolmogorov-Smirnov test. For the cases of 9 to 14 displayed targets, the mean of the selected distributions varied from 12.24 to 18.63 seconds. The corresponding number of actions per second (1/T) are .081699 to .053677.

The reaction time data for the tracking task was to be processed in the same manner as that used for the detection task, but an unexpected difficulty arose. The experimental subjects had anticipated targets crossing range markers with the result that there were many reaction times

equal to zero. Probably the chief cause was that the accuracy of the printed data was only to the nearest second. To allow a comparison with the data for detection tasks, the zeroes were censored and the reaction time data for tracking tasks were processed as before. Results were:

Number of Targets on Display	Distribution Selected	Parameters		Mean (Sec)	Variance
2	Normal	$\mu = 2.600$	$\sigma = 1.32$	2.600	1.74
3	Log-Normal	$\mu = .8039$	$\sigma = .8665$	3.252	11.83
4	none	-		-	-
5	Ext Value-Largest	$\beta = 2.184$	$\mu = 2.264$	3.525	7.85
6	none	-		-	-
7	Log-Normal	$\mu = 1.054$	$\sigma = .8142$	4.000	15.02
8	Log-Normal	$\mu = 1.408$	$\sigma = .9783$	6.596	69.80
9	Log-Normal	$\mu = 1.710$	$\sigma = 1.080$	9.907	216.93
10	none	-		-	-
11	Log-Normal	$\mu = 1.756$	$\sigma = 1.013$	9.671	167.43
12	none	-		-	-
13	Log-Normal	$\mu = 1.645$	$\sigma = 1.222$	10.931	412.46
14	Log-Normal	$\mu = 1.777$	$\sigma = .9078$	8.927	101.99

VI. Conclusions and Recommendations for Future Study

Conclusions

Based upon the results discussed in Chapter V, the saturation level of the human operator modeled by means of the concept of the ideal operator can be described with the extreme value - largest probability distribution. Added credence is lent to this result when the works of Gumbel (Ref 8) and Singpurwalla (Ref 20) are considered. Gumbel points out that the characteristic largest value of the normal, logistic, and exponential distributions are distributed according to the extreme value-largest distribution. Singpurwalla shows in Ref 20 that the characteristic largest value of the lognormal distribution has an extreme value distribution.

The mean saturation levels of 10.7 to 12.8 targets calculated in Chapter V support the 10 target expectation of the radar operator school graduates as reported by Thomas (Ref 22:68) and are in agreement with Kidd's conjecture (Ref 13).

Modeling human saturation level using reaction time data results in a serious underestimation of saturation level. This underestimation is apparent when the mean reaction times of Chapter V are compared to the results shown in Tables IV through VI in Appendix E. The mean reaction times indicate much lower saturation levels than were actually observed.

According to the results of the sign test and the Monte Carlo simulation discussed in Chapter V, the primary conclusion of this thesis is that the saturation level of the human radar operator may be modeled by the extreme value-largest probability distribution where μ varies depending upon rate of target introduction while β is constant (approximately equal to .0067).

Recommendations for Future Study

To most effectively utilize the principal features of this work, the following recommendations are proposed:

1. A method of modeling human saturation level has been developed. More accurate results can be achieved by modifying the prototype and measuring the responses of actual operators in a more realistic environment, possibly an operational radar site.

2. Assuming accurate radar operator saturation levels are available, the problem of allocating radar operators to a radar system can be approached.

3. It is possible that the concept of the ideal operator can be extended, with appropriate modification, to the problem of modeling the reliability of electronic or mechanical parts under accelerating stress.

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Appendix A

INSTRUCTIONS TO SUBJECT:

1. You are participating in an experiment which is designed to test the performance of radar operators. The task you will be asked to perform consists of the two jobs that radar operators are required to do. These are detection of new targets and tracking of already detected targets. You will be asked to monitor only about one fourth of the radar screen.

2. Detection Task. Whenever you first notice a new target appear on the screen in your assigned sector, you will note the position of the target with a grease pencil and assign it a number. For scoring purposes, position the azimuth cursor over the target, press the button and at the same time announce the number aloud. New targets will appear on the screen at random time intervals, but will always appear in the range between 60 and 80 miles.

3. Tracking Task. Each target must also be tracked as long as it is on the scope in your sector. You will indicate that you are tracking a target by announcing each time it crosses a range marker. Your announcement is made as before, the azimuth cursor is placed over the target, the button is pushed, and the target number is announced aloud at the same time.

4. Priority of Work. If you think you must chose between tracking a few targets well or many targets poorly, remember that, in a real situation, the operator would be instructed to do his best on a smaller number of targets.

Appendix B

Generation of Simulation Tapes

Because the SATSIM software support package does not include provisions for simulating more than four targets at one time, it was necessary to develop a computer program that would generate digital magnetic tapes containing the appropriate information. This appendix describes the necessary tape format and the program that was written to generate these simulation tapes.

SATSIM Input Format

Information for many SATSIM simulation runs can be contained on one standard length digital magnetic tape. The total cumulative running time is limited to about 25 minutes. For each simulation run on the tape, the following format is used:

1. The first data record, a header record, indicates the file number and the run number of the simulation run. These numbers are handy if a large number of tapes are being handled.

2. The second and subsequent data records, sector records, each contain information relating to 250 PRF's. Because the simulated radar has an antenna scan rate of 6 revolutions per minute and a PRF of 400 pulses per second, one data record corresponds to 22-$\frac{1}{2}$ degrees of azimuth. Each PRF corresponds to 1/4000 of a complete 360 degree scan, or .09 degrees (5 minutes, 24 seconds of arc).

Simulation runs are separated by end-of-record blocks. The last simulation run on a tape must be followed by two end-of-record blocks.

Header Record Format. The header record is formed by writing two CDC 6600 words on to the tape. The first word is the file number and the second word is the run number.

Sector Record Format. On magnetic tape the smallest unit of information that can be written at one time is the six-bit byte. Two of these bytes are combined upon input to the PDP-8 to form a 12-bit word. Each sector record contains 3000 of these 12-bit words which means there are 12 words per PRF. Each 12-word section is composed of:

1. Four jammer words. Because it is not necessary to simulate jamming, this portion of the data record is set to zeroes.

2. Four target intensity words. Target intensity information is specified separately for targets appearing on channels 1 through 4. If no targets appear on a particular channel during the current PRF, the appropriate word is set to zero. Maximum target intensity is 1777_8. For this simulation target intensities were uniformly set to 1720_8.

3. Four target range words. Target range information is also specified separately for targets appearing on Channels 1 through 4. The maximum range that can be displayed at a PRF of 400 pulses per second is approximately 80 miles which corresponds to 1777_8. The displayed range is directly proportional to the range word so that the displayed range in miles, r_d, is:

$$r_d = \text{range word} * 80 \text{ miles}/1777_8$$

Tape Generation Program

The FORTRAN computer program which was developed to generate the

SATSIM input tapes is included as Appendix C. A block diagram of the main program is given as Fig. 8. Each tape that is generated contains two 10-minute simulation runs. The main program is designed so that the first time it is run in a two-run sequence, it rewinds the output tape before writing, and after writing produces one end-of-record. For the second run, the output tape is not rewound and an end-of-record is written twice. Operation of the program is the same in all other respects for both runs.

The first step in the program is to write a header record onto the magnetic tape. Since a large number of tapes are not necessary, the same header is written for all simulation runs. The subroutine READIN is then called. This subroutine reads information which specifies the location and time at which targets are to appear on the display. A DO loop is then entered which is executed once for each complete rotation of the simulated radar antenna. The first step in the loop is to call subroutine CALCPOS which calculates the position of all targets which are to appear on the current scan. Then the subroutine OUTPUT is called to write the calculated information onto the magnetic tape. After the last scan has been completed, an end-of-record is written onto tape. Details of each subroutine are given below.

<u>Subroutine READIN</u>. The subroutine READIN is used to initialize many of the often used program constants as well as to read in target information. The target information is read from cards and consists of:

1. The time, measured in minutes after the beginning of the simulation run, at which the target is to appear on the display.

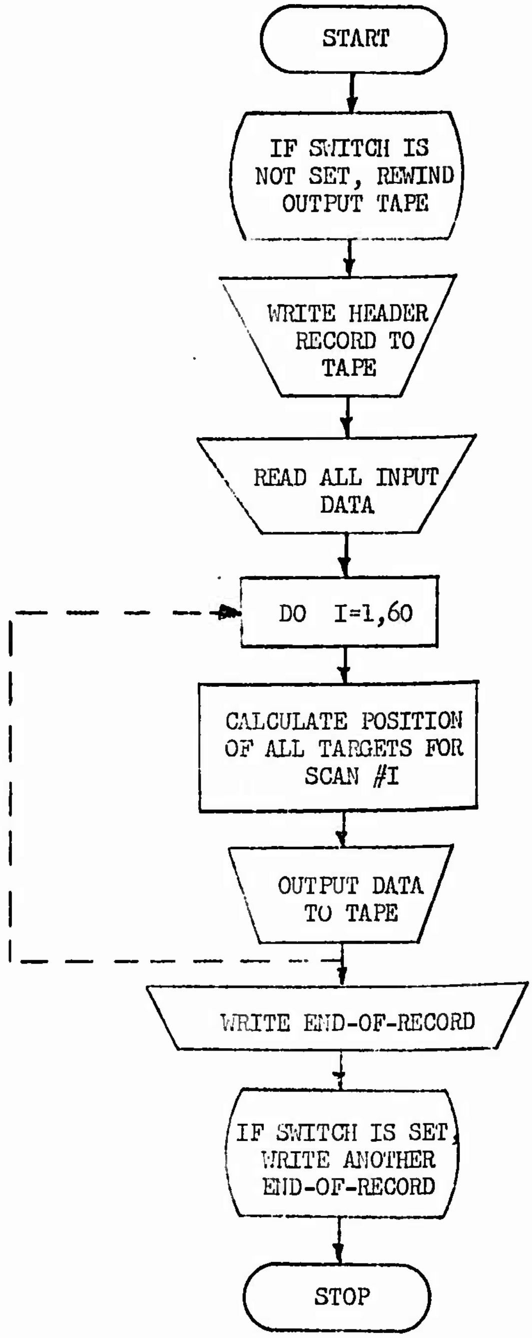

Fig. 8. Tape Generation Program Block Diagram

2. The X- and Y-coordinates, measured in miles, of the initial position of the target. The origin of the X-Y coordinate system is the center of the display and the positive Y-axis is in the vertical (North) direction.

3. The velocity of the target in miles per minute.

4. The X- and Y-coordinates of the final position of the target, measured in miles.

Target information for Channel 1 is input to the subroutine in increasing order of time of appearance. Information then follows for targets appearing on channels 2, 3, and 4.

Each target has the following information stored in a master array:

1. The scan number at which the target is to appear.
2. The scan number at which the target is to disappear.
3. The initial X-position of the target.
4. The initial Y-position of the target.
5. The incremental distance that the target will move in the X-direction on each scan.
6. The incremental distance that the target will move in the Y-direction on each scan.

Also stored for future reference are the number of targets appearing on each channel for the simulation run. These values are placed in common storage.

Subroutine CALCPOS. Subroutine CALCPOS calculates the position of each active target, those that are to appear on the current scan. To do this the subroutine checks the master array generated by READIN for tar-

gets which appeared on an earlier scan and will disappear on some future scan. If an active target is found, its position in the X-Y coordinate system is converted to the polar form. The azimuth is measured in terms of PRF number, from 1 through 4000, rather than degrees. The range from the origin is converted to the form used by the PDP-8.

After all positions have been calculated, the azimuth, range, and channel number information for all targets is sorted by azimuth. The subroutine that does the sorting, QUICKY, is an assembly language (COMPASS) quicksort subroutine.

Subroutine OUTPUT. Subroutine OUTPUT builds an array of target information and then writes the array onto magnetic tape. For each scan of the simulated radar antenna, OUTPUT writes 16 blocks of data; each block represents 22-$\frac{1}{2}$ degrees of scan.

The subroutine first zeroes the entire array. Next, a check is made to see if there are any targets in the next sector. If not, the zeroes are written onto the tape. If targets are found in the array built by CALCPOS, the intensity and range information is stored so that the target will appear on seven consecutive PRF's of the display. One 60-bit CDC 6600 word is used to store data for all four of the data channels by shifting the 12 bits of information an appropriate amount depending upon the channel number of the target. Channel 4 information is stored in the lowest 12 bits of the word, Channel 3 data is shifted 12 bits to the left, Channel 2 data is shifted 24 bits, and Channel 1 data is shifted 36 bits.

In the final three-column by 250-row array, the first column which represents jammer information, is filled with zeroes. The second column contains intensity information for all channels and the third column con-

tains range information for four channels. Each row of the array represents one PRF. The most significant 12 bits of each word in the array are filled with zeroes. Before the data can be written onto magnetic tape, the data must be compressed to form a 600-word array with the high order 12 bits of each word removed. This is the purpose of the subroutine SQUEEZE. Data is then written onto tape using the FORTRAN buffer-out statement.

Appendix C

Tape Generating Program

```
      PROGRAM YYY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
      INTEGER IN(2)
      COMMON V(5,400)
      CALL SSWTCH(1,ISWTCH)
      IF(ISWTCH.EQ.1) GO TO 10
      REWIND 2
10    IN(1)=1
      IN(2)=1
      BUFFER OUT(2,1)(IN(1),IN(2))
      IO=UNIT(2)
      CALL READIN
60    DO 100 I=1,60
      CALL CALCPOS(I)
      CALL OUTPUT
100   CONTINUE
      ENDFILE 2
      IF(ISWTCH.EQ.2) GO TO 999
      ENDFILE 2
999   STOP
      END
```

```
      SUBROUTINE READIN
      COMMON /INITIAL/ IRA(4), IRAMP(4),MASK
      COMMON V(5,400)
C     THIS SUBROUTINE READS IN ALL THE DATA AND STORES IT
C     IN THE ARRAY V(5,N) WHERE N IS THE NUMBER OF TARGETS.
C     ALSO RETURNED IS LIMIT(1) THRU LIMIT(4) WHICH ARE THE
C     LAST TARGETS STORED FOR CHANNELS 1 THRU 4.
C
C     V(1,I) = THE INITIAL SCAN NUMBER FOR THE I TH TARGET
C     V(2,I) = THE FINAL SCAN NUMBER FOR THE I TH TARGET
C     V(3,I) = THE PRESENT X POSITION OF THE I TH TARGET
C     V(4,I) = THE PRESENT Y POSITION OF THE I TH TARGET
      REAL LTIME, IT
      COMMON /REST/ MAX, LIMIT(4),IOUT(600)
      MASK = 7777B
      IRA(1) = SHIFT(MASK,36)
      IRA(2) = SHIFT(MASK,24)
      IRA(3) = SHIFT(MASK,12)
      IRA(4) = MASK
      IRAMP(4)=1720B
      IRAMP(3) = SHIFT(IRAMP(4),12)
      IRAMP(2) = SHIFT(IRAMP(3),12)
      IRAMP(1) = SHIFT(IRAMP(2),12)
      I=1
      J=1
      LTIME=0.0
 1    READ(5,901) IT
      IF(EOF(5)) 200,5
 5    IF(IT.GE.LTIME) GO TO 10
      LIMIT(J)=I-1
      IF(J.EQ.4) GO TO 200
      J=J+1
 10   READ(5,902) X1,Y1,VL,X2,Y2
 20   K=6.0*IT
      V(1,I)=K
      DT=SQRT((X1-X2)**2 + (Y1-Y2)**2)
```

```
      TIME=DT*60./VL
      K=1 + 6.0*(IT + TIME)
      V(2,I)=K
      V(3,I)=X1
      V(4,I)=Y1
      V(5,I)=(X2-X1)/(6.*TIME)
      V(6,I)=(Y2-Y1)/(6.*TIME)
      I=I+1
      LTIME=IT
      GO TO 1
20    LIMIT(J)=I-1
901   FORMAT(10X,F10.3)
902   FORMAT(2F10.3,10X,3F10.3)
      RETURN
      END
```

```
      SUBROUTINE CALCPOS(N)
      COMMON V(5,400)
      INTEGER LWLIM(4)
      COMMON /REST/ MAX, LIMIT(4),IOUT(600)
10    RN=N
      MAX=1
      LWLIM(1)=1
      LWLIM(2) = LIMIT(1) + 1
      LWLIM(3) = LIMIT(2) + 1
      LWLIM(4) = LIMIT(3) + 1
      DO 200 I=1,4
      JJJ=LIMIT(I)
      III=LWLIM(I)
      DO 100 J=III,JJJ
      IF(V(1,J).GT.RN) GO TO 200
      IF(V(2,J).LT.RN) GO TO 100
      IF(V(4,J).EQ.0.0) V(4,J) = .0001
      ANG=ATAN( V(3,J)/V(4,J) )
      IF(V(3,J).LT.0.0) GO TO 21
      IF(V(4,J).GE.0.0) GO TO 212
      GO TO 211
21    IF( V(4,J).GT.0.0) ANG = ANG +3.14159
211   ANG = ANG + 3.14159
212   IANG = ANG/6.28318*4096
      RAN=SQRT( V(3,J)**2 + V(4,J)**2 )
      V(3,J) = V(3,J) + V(5,J)
      V(4,J) = V(4,J) + V(5,J)
      IRAN =(RAN/80.)*1023.
      IF(IRAN.GE.1024) IRAN = 1777B
      IOUT(MAX)= SHIFT(IANG,24)  + SHIFT(IRAN,12)  + I
20    MAX = MAX + 1
100   CONTINUE
200   CONTINUE
      MAX = MAX - 1
      IJK=MAX
      CALL QUICKY(IJK,IOUT)
```

```
RETURN
END
```

```
      SUBROUTINE OUTPUT
      COMMON /INITIAL/ IRA(4), IRAMP(4),MASK
      COMMON /OUT/ ISTORE(3,257)
      COMMON /REST/ MAX,LIMIT(4),IOUT(600)
      ISTOP=0
      IF(MAX.EQ.1) ISTOP=1
      IFLAG=0
      I=1
      IJK=0
      DO 200 J=IJK,375 ,250
      MAXANG = J + 250
      DO 20 K=1,7
      ISTORE(1,K)=0
      ISTORE(2,K)=ISTORE(2,250+K)
   20 ISTORE(3,K)=ISTORE(3,250+K)
      DO 25 K=8,257
      ISTORE(1,K) = 0
      ISTORE(2,K) = 0
   25 ISTORE(3,K) = 0
   40 IF(ISTOP.EQ.1) GO TO 99
      IANG = SHIFT(IOUT(I),-24).AND.MASK
      IF (IANG.GT.MAXANG) GO TO 99
      GO TO 50
   45 IANG = SHIFT(IOUT(I),-24).AND.MASK
      IF (IANG.GT.MAXANG) GO TO 100
   50 ICHAN = IOUT(I).AND.MASK
      IRAN = SHIFT(IOUT(I),-12).AND.MASK
      DO 75 K=1,7
      INDEX = K + IANG - J - 1
C    THIS IS FOR AMPLITUDE
      ISTORE(2,INDEX) = ISTORE(2,INDEX).OR.IRAMP(ICHAN)
C
C    THIS IS FOR RANGE
      IX = (4 - ICHAN)*12
   75 ISTORE(3,INDEX)=(ISTORE(3,INDEX).AND..NOT.IRA(ICHAN))
     1.OR.SHIFT(IRAN,IX)
```

```
      IF(I.EQ.MAX) ISTOP=1
      IF(ISTOP.EQ.1) GO TO 100
      I=I+1
      GO TO 45
 99   IFLAG = 1
 100  CONTINUE
      CALL SQUEEZE(ISTORE)
      BUFFER OUT (2,1)(ISTORE(1,1),ISTORE(3,200))
 200  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SQUEEZE (IARRAY)
      INTEGER IARRAY (750), IJ(120)
      ENCODE (80,990,IJ(1)) IARRAY
      DECODE(80,991,IJ(1))(IARRAY(I),I=1,600)
      RETURN
990   FORMAT(50I6)
991   FORMAT (40I2)
      END
```

Appendix D

Data Analysis Program

```
      PROGRAM XXXXY(INPUT,OUTPUT,TAPE5=INPUT)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      INTEGER DN(20),TITLE(6),NAME(4,20)
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NO=11
1     READ(5,901) TITLE,N
901   FORMAT(6A10,I5)
      IF(EOF(5)) 990,5
5     READ (5,902) (X(I),I=1,N)
902   FORMAT(7F10.2)
      CALL QUICKY(N,X)
      PRINT 9025,TITLE,N
      PRINT 903,(X(I),I=1,N)
      KSV=RKS(N)
      SUM1=SUM2=SUM3=SUM4=0
      DO 100 I=1,N
      SUM1=SUM1 + X(I)
      SUM2=SUM2 + X(I)**2
      SUM3=SUM3 + ALOG(X(I))
100   SUM4=SUM4 + (ALOG(X(I))**2)
      CALL UNIFORM(1)
      CALL EXPON(2)
      CALL WEIBULL(3)
      CALL NORMALD(4)
      CALL LOGNORM(5)
      CALL GAMMAD(6)
      CALL LOGIST(7)
      CALL EVSMALL(8)
      CALL EVLARGE(9)
      CALL PARETO(10)
      CALL LAPLACE(11)
      PRINT 904,TITLE
      DO 150 I=1,NO
150   PRINT 905,NAME(1,I),NAME(2,I),NAME(3,I),A(I),
     1 NAMEW(4,I),B(I)
```

```
      PRINT 906,KSV
      DO 200 I=1,NO
200   PRINT 907,NAME(1,I),NAME(2,I),VKS(I),DN(I)
      PRINT 908
      DO 250 I=1,NO
250   PRINT 909, NAME(1,I), NAME(2,I), LNL(I)
      PRINT 910
      FLAG=0
      DO 300 I=1,NO
      IF(DN(I).NE.10HACCEPT      ) GO TO 300
      IF(FLAG.EQ.1) GO TO 280
      FLAG=1
      J=I
      GO TO 300
280   IF(LNL(J).LT.LNL(I)) J=I
300   CONTINUE
      IF(FLAG.EQ.0) GO TO 400
      PRINT 911, NAME(1,J),NAME(2,J),NAME(3,J),A(J),NAME(4,J),B(J)
      GO TO 1
400   PRINT 912
      GO TO 1
999   STOP
902   FORMAT(*1*,10X,6A10,//,10X,*INPUT DATA CONSISTED OF-*,I5,* POINTS*
     1,//)
903   FORMAT(10(2X,F10.6))
904   FORMAT(*1*,10X,6A10,// ,* PART I.  PARAMETER ESTIMATION*,
     1//,5X,*DISTRIBUTION*,16X,*PARAMETER 1*,15X,
     2*PARAMETER 2*,/)
905   FORMAT(5X,2A10,5X,A10,1X,E10.4,5X,A10,1X,E10.4)
906   FORMAT(/ ,* PART II.  KOLMOGOROV-SMIRNOV TEST (MAX DVALUE =*
     1,F7.5,*)*,//5X,*DISTRIBUTION*,13X,*MAX KSVALUE*,5X,
     2*DECISION*,/)
907   FORMAT(5X,2A10,7X,F7.5,7X,A10)
908   FORMAT(/ ,* PART III.  LIKELIHOOD RATIO TEST.*,//,5X,
     1*DISTRIBUTION*,13X,*LN OF LIKELIHOOD FUNCTION*,/)
909   FORMAT(5X,2A10,7X,F7.0)
```

```
910  FORMAT(/ ,* PART IV.  DECISION.*,/ )
911  FORMAT(* THE LIKELIHOOD RATIO AND KOLMOGOROV-SMIRNOV TESTS *
    1,*HAVE SELECTED THE *,2A10,/,* DISTRIBUTION.  PARAMETERS ARE:*
    2,/,10X,A10,E10.4,5X,A10,E10.4)
912  FORMAT(* NO DISTRIBUTION WAS SELECTED.*)
     END
```

```
      SUBROUTINE UNIFORM (K)
      INTEGER DN(20),TITLE(6),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HUNIFORM
      NAME(2,K)=10H
      NAME(3,K)=10HALPHA =
      NAME(4,K)=10HBETA =
C        PARAMETER ESTIMATION
      A(K)= X(1)
      B(K)= X(N)
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F=  (X(I)-A(K))/(B(K)-A(K))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F= 1.0/(B(K)-A(K))
  200 LNL(K)=LNL(K)  + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE EXPON(K)
      INTEGER DN(20),TITLE(6),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HEXPONENTIA
      NAME(2,K)=10HL
      NAME(3,K)=10HTHETA =
      NAME(4,K)=10HMU =
C        PARAMETER ESTIMATION
      A(K)= X(1)
      B(K)= SUM1/N-A(K)
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F= 1.0 - EXP(-(X(I)-A(K))/B(K))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C       LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F= EXP(-(X(I)-A(K))/B(K))/B(K)
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE WEIBULL(K)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      INTEGER DN(20),TITLE(6),NAME(4,20)
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HWEIBULL
      NAME(2,K)=10H
      NAME(3,K)=10HBETA =
      NAME(4,K)=10HALPHA =
C        PARAMETER ESTIMATION
      A(K)=1./(((SUM4/(N-1)-(SUM3**2)/(N*(N-1)))*(.6079271))** .5)
      B(K)=EXP(SUM3/N+.5772/A(K))
C       KS TEST
      VKS(K)
      DO 1
      SS=FL        FLOAT(N)
      F= 1.0-EXP(-(X(I)/B(K))**A(K))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
   10 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F= (A(K)/B(K))*EXP(-(X(I)/B(K))**A(K))*((X(I)/B(K))**(A(K)-1.))
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE NORMALD(K)
      INTEGER DN(20),TITLE(6),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      REAL M
      COMMON/NORM/M,S
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HNORMAL
      NAME(2,K)=10H
      NAME(3,K)=10HMU =
      NAME(4,K)=10HSIGMA =
C        PARAMETER ESTIMATION
      A(K)= SUM1/N
      B(K)= (SUM2/N-A(K)**2)**.5
      M=A(K)
      S=B(K)
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      CALL NORMAL(X(I),V)
      F= 1.0 - V
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F= FUN(X(I))
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE LOGNORM(K)
      INTEGER DN(20),TITLE(6),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      REAL M
      COMMON/NORM/M,S
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HLOG-NORMAL
      NAME(2,K)=10H
      NAME(3,K)=10HMU =
      NAME(4,K)=10HSIGMA =
C        PARAMETER ESTIMATION
      A(K)= SUM3/N
      B(K)=(SUM4/(N-1)-SUM3**2/(N*(N-1)))**.5
      M=A(K)
      S=B(K)
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      CALL NORMAL(ALOG(X(I)),V)
      F=1.-V
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F= FUN(ALOG(X(I)))/X(I)
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE GAMMAD(K)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      INTEGER DN(20),TITLE(5),NAME(4,20)
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,SUM4,NAME
      NAME(1,K)=10HGAMMA
      NAME(2,K)=10H
      NAME(3,K)=10HALPHA =
      NAME(4,K)=10HBETA =
C        PARAMETER ESTIMATION
      Y=ALOG(SUM1/N)-SUM3/N
      A(K)=(1.+(1.+1.333333*Y)**.5)/(4.*Y)
      B(K)=(SUM1/N)/A(K)
      IF(A(K).GT.40) GO TO 400
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F=FINT(X(I),A(K),B(K))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F=EXP(-X(I)/B(K))*(X(I)**(A(K)-1.))/(GAMMA(A(K))*(B(K)**A(K)))
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
  400 VKS(K)=.999999
      LNL(K)=-99999
      DN(K)=10HREJECT
      RETURN
      END
```

```
      SUBROUTINE LOGIST(K)
      INTEGER DN(20),TITLE(6),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HLOGISTIC
      NAME(2,K)=10H
      NAME(3,K)=10HMU =
      NAME(4,K)=10HSIGMA =
C        PARAMETER ESTIMATION
      A(K)= SUM1/N
      B(K)= (SUM2/N-(SUM1/N)**2)**.5
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F=1.0/(1.+EXP(-1 81379936*(X(I)-A(K))/B(K)))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      ST=1.81379936/B(K)
      DO 200 I=1,N
      F=ST*EXP(-ST*(X(I)-A(K)))/((1.+EXP(-ST*(X(I)-A(K))))**2)
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE EVSMALL(K)
      INTEGER DN(20),TITLE(6),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HEXT VALUE-
      NAME(2,K)=10HSMALLEST
      NAME(3,K)=10HBETA =
      NAME(4,K)=10HMU =
C        PARAMETER ESTIMATION
      A(K)= .7796968*((SUM2/N-(SUM1/N)**2)**.5)
      B(K)= SUM1/N+.5772*A(K)
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F=1.0-EXP(-EXP((X(I)-B(K))/A(K)))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      ST=(X(I)-B(K))/A(K)
      F=     EXP(ST-EXP(ST))/A(K)
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE EVLARGE(K)
      INTEGER DN(20),TITLE(5),NAME(4,20)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HEXT VALUE-
      NAME(2,K)=10HLARGEST
      NAME(3,K)=10HBETA =
      NAME(4,K)=10HMU =
C        PARAMETER ESTIMATION
      A(K)= A(K-1)
      B(K)= SUM1/N-.5772*A(K)
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F=     EXP(-EXP(-(X(I)-B(K))/A(K)))
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      ST=-(X(I)-B(K))/A(K)
      F=     EXP(ST-EXP(ST))/A(K)
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE PARETO(K)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      INTEGER DN(20),TITLE(6),NAME(4,20)
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HPAR TO
      NAME(2,K)=10H
      NAME(3,K)=10HK =
      NAME(4,K)=10HA =
C        PARAMETER ESTIMATION
      A(K)=X(1)
      B(K)=N/(SUM3-N*ALOG(A(K)))
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      F=1.0-(A(K)/X(I))**B(K)
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F=B(K)*(A(K)**B(K))/(X(I)**(B(K)+1.))
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
      END
```

```
      SUBROUTINE LAPLACE(K)
      REAL X(1000),A(20),B(20),LNL(20),VKS(20),KSV
      INTEGER DN(20),TITLE(6),NAME(4,20)
      COMMON/BLOCK/X,N,A,B,LNL,VKS,KSV,DN,SUM1,SUM2,SUM3,
     1 SUM4,NAME
      NAME(1,K)=10HLAPLACE
      NAME(2,K)=10H
      NAME(3,K)=10HTHETA =
      NAME(4,K)=10HPHI =
C        PARAMETER ESTIMATION
      M=N/2
      A(K)=X(M)
      B(K)=(SUM1-N*A(K))/N
      IF(B(K).LE.0) GO TO 400
C       KS TEST
      VKS(K)=0
      DO 100 I=1,N
      SS=FLOAT(I)/FLOAT(N)
      IF(X(I).GT.A(K)) GO TO 50
      F=.5*EXP(-(A(K)-X(I))/B(K))
      GO TO 55
   50 F=1.-.5*EXP(-(X(I)-A(K))/B(K))
   55 CONTINUE
      TEMP=ABS(SS-F)
      IF(TEMP.GT.VKS(K)) VKS(K)=TEMP
  100 CONTINUE
C      LIKELIHOOD CALCULATION
      LNL(K)=0
      DO 200 I=1,N
      F=EXP(-ABS(X(I)-A(K))/B(K))/(2*B(K))
  200 LNL(K)=LNL(K) + ALOG(F)
      IF(VKS(K).LE.KSV) GO TO 300
      DN(K)=10HREJECT
      RETURN
  300 DN(K)=10HACCEPT
      RETURN
```

```
40    LNL(K)=-99999
      VKS(K)=1.
      DN(K)=10HREJECT
      RETURN
      END
```

```
      SUBROUTINE NORMAL (X,V)
      REAL M,S,X,V
      COMMON/NORM/M,S
      TOL=1E-6
      V=0
      IF(X.GE.M+S*10.) GO TO 900
      YO=FUN(X)
      YN=FUN(M+10*S)
      N=20
      H=(M+10*S-X)/N
      SUMEV=0
      DO 10 I=2,18,2
10    SUMEV=SUMEV+FUN(X+I*H)
15    SUMOD=0
      K=N-1
      DO 20 I=1,K,2
20    SUMOD=SUMOD+FUN(X+I*H)
      TEMP=V
      V=(1./3.)*H*(YC+YN+4.*SUMOD+2.*SUMEV)
      IF(ABS(TEMP-V).LT.TOL) GO TO 900
      SUMEV=SUMEV+SUMOD
      N=2*N
      H=(M+10*S-X)/N
      GO TO 15
900   RETURN
      END
```

```
FUNCTION RINT(X,A,B)
RINT=((X/B)**A)*DFUN(A,X/B)/GAMMA(A)
RETURN
END
```

```
FUNCTION FUN(X)
COMMON/NORM/M,S
REAL M
FUN=.39894228*EXP(-((X-M)**2)/(2*S**2))/S
RETURN
END
```

```
REAL FUNCTION RKS(N)
RKS=1.07/(N**.5)
RETURN
END
```

```
      FUNCTION GAMMA(XX)
      IF(XX-57.) 6,6,4
4     GAMMA=1.E75
      RETURN
6     X=XX
      ERR=1.0E-6
      GAMMA=1.0
      IF(X-2.0)50,50,10
10    IF(X-2.0)110,110,15
15    X=X-1.0
      GAMMA=GAMMA*X
      GO TO 10
50    IF(X-1.0)60,120,110
60    IF(X-ERR)62,62,80
62    Y=FLOAT(INT(X))-X
      IF(ABS(Y)-ERR)130,130,64
64    IF(1.0-Y-ERR)130,130,70
70    IF(X-1.0)80,80,110
80    GAMMA=GAMMA/X
      X=X+1.0
      GO TO 70
110   Y=X-1.0
      GY=1.+Y*(-.5771017+Y*(.9858540+Y*(-.8764218+Y*(.8328212+
     1Y*(-.5684729+Y*( 2548205+Y*(-.0514993)))))))
      GAMMA=GAMMA*GY
120   RETURN
130   GAMMA=1.
      RETURN
      END
```

```
      FUNCTION DFUN(RN,X)
      IF(X.LE.0) GO TO 70
      TOL=(1E-5)*X
      SUM=ROLD=1./RN
      DO 25 I=1,25
      RNEW=ROLD*X/(RN+I)
      SUM=SUM+RNEW
25    ROLD=RNEW
      DO 50 I=26,100
      RNEW=ROLD*X/(RN+T)
      SUM=SUM+RNEW
      IF((RN+I-X).EQ.0.0) GO TO 50
      VAL1=ROLD*X/(RN+I-X)
      VAL2=TOL*SUM
      IF(VAL1.LE.VAL2) GO TO 60
50    ROLD=RNEW
      DFUN=0
      RETURN
60    DFUN=EXP(-X)*SUM
      RETURN
70    DFUN=0
      RETURN
      END
```

```
         IDENT  QUICKY
         ENTRY  QUICKY
COMP     BSS    1
SWITCH   BSS    1
STACK    BSS    20
TEMP     BSS    1
QUICKY   BSS    1
         SX6    A1
         SA6    TEMP          SAVE A1
         SB7    1             B7=1
         SB6    B7+B7         B6=2
         SA2    X1            READ M INTO X2
         BX7    X2
         SA7    STACK         PUT M INTO STACK
         SA3    A1+B7
         BX6    X3
         SB1    STACK
         SA6    B1+B7
         SB2    STACK+B6
T        SA4    X3
         SX3    X3+B7
         ZR     X4,T
         MX5    12
         BX7    X4*X5
         ZR     X7,T1
         BX4    -X4
         BX7    X4*X5
         ZR     X7,T1
         SX6    B7
         SA4    A1+B6
         SA6    X4
         EQ     T2
T1       SX6    B6
         SA4    A1+B6
         SA6    X4
T2       SA6    B6
```

```
         SX6    B1
LABLE    EQ     B1,B2,DONE  IF POINTER AT TOP OF STACK QUIT
         SB2    B2-B5
         SA1    B2
         SB5    X1
         SX1    B5-B6
         NG     X1,LABLE
*  IF EQU ALS TW O CHECK AND SWITCH IF NECESSARY
         GT     B5,B6,CONT
         SA1    B2+B7
         SA2    X1
         SA3    X1+B7
         IX4    X3-X2
         PL     X4,LABLE
         BX6    X3
         BX7    X2
         SA6    A2
         SA7    A3
         EQ     LABLE       GO BACK FOR MORE
CONT     SA1    B2+B7
         SB3    X1
         SB4    B3+B5
         SB4    B4-B7       PDWN=XXX+N-1
*  IF VAL UE AT PUP>PDWN SWITCH
         SA3    B3
         SA4    B4
         IX5    X4-X3
         PL     X5,GO
         BX6    X3
         BX7    X4
         SA6    A4
         SA7    A3
         SA1    A7
         SA2    A6
         EQ     GOT
GO       SA1    A3
```

```
              SA2    A.
*  NOW X1 IS LOW X2=HIGH
*  NOW RUN PUP DOWN
GOT           SA3    A3+B7
              SX5    A3
              SX6    A4
              IX5    X5-X6
              ZR     X5,S4
              IX5    X1-X3
              PL     X5,GOT
 TO           SA4    A4-B7
              SX5    A3
              SX6    A4
              IX5    X5-X6
              ZR     X5,S5
              IX5    X4-X2
              PL     X5,TO
              IX5    X4-X3
              PL     X5,GO
              BX6    X3
              BX7    X4
              SA6    A4
              SA7    A3
              SA3    A3-B7
              SA4    A4+B7
              EQ     GOT
 S4           SA5    A3-B7
              BX7    X5
              SA7    A1
              BX6    X1
              SA6    A5
              BX7    X3
              SA7    A2
              BX6    X2
              SA6    A3
 FIN          SX3    A3-B3
```

```
          SX3     X3-1
          SX4     A3-B4
          BX4     -X4
          IX5     X3-X4
          PL      X5,HI
          BX7     X4
          BX6     X3
          SX4     A3+B7
          SX3     B3
          EQ      HH
HI        BX6     X4
          BX7     X3
          SX4     B3
          SX3     A3+B7
HH        SA7     B2
          SA6     B2+B6
          BX6     X3
          BX7     X4
          SA7     B2+B7
          SA6     A7+B6
          SB2     A6+B7
          EQ      LABLE
S5        IX5     X5-X2
          PL      X5,S4
          BX7     X1
          SA5     A3-B7
          SA7     A5
          BX6     X5
          SA6     A1
          EQ      FIN
DONE      EQ      QUICKY
     END
```

Appendix E

Experimental Data

The data taken during the experiment with the twenty subjects is presented in the tables which follow.

TABLE IV

Reaction Times in Seconds - Run 2

SUBJECT

ACTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
*1	4	4	4	3	3	5	3	4	4	5	5	3	3	5	5	5	3	3	6	5
*2	3	3	5	3	4	4	2	3	5	4	4	4	3	2	5	4	3	4	4	4
*3	8	9	7	5	9	9	5	8	14	7	7	6	6	7	8	9	6	7	7	7
4	0	0	0	1	4	0	0	3	2	0	2	0	2	2	11	0	1	1	0	0
5	0	0	0	0	0	0	0	2	2	0	0	0	0	0	6	0	0	0	0	0
*6	4	8	8	3	6	15	1	4	3	5	8	5	5	2	2	1	1	2	2	4
7	9	1	4	5	1	5	3	10	7	1	2	0	1	12	17	4	4	12	0	0
*8	2	3	16	3	4	2	1	3	3	13	3	2	3	2	2	2	0	3	2	3
9	3	2	4	4	5	0	0	3	11	1	2	6	-	7	8	2	0	4	11	3
*10	7	9	11	6	8	16	4	7	5	7	8	2	3	3	2	4	4	5	1	6
11	4	3	23	3	1	12	1	2	3	0	3	1	-	10	12	1	1	4	0	-
*12	22	13	13	8	3	36	12	13	5	7	14	12	3	6	5	3	13	12	5	8
13	9	1	7	5	19	3	3	7	26	4	5	4	0	1	-	6	3	-	50	42
*14	8	4	16	5	13	19	12	8	23	2	16	4	4	6	13	3	48	26	0	4
15	1	1	3	3	3	-	2	3	14	1	3	0	0	3	11	[illegible]	2	22	-	-
16	2	1	4	14	10	0	0	6	2	17	3	0	0	0	1	-	2	-	0	2
17	7	0	0	0	0	30	0	2	1	1	4	5	0	0	0	-	1	0	0	0
*18	11	3	11	4	7	20	12	8	6	5	29	4	3	2	5	3	4	3	-	4
19	2	0	4	6	0	-	0	1	2	0	20	45	0	12	23	16	9	-	0	1
20	8	3	14	12	2	0	-	13	25	8	1	1	1	4	5	0	43	3	0	2
*21	21	4	42	25	5	3	-	17	4	5	37	43	2	22	14	25	41	34	0	45
22	43	3	1	2	9	11	11	25	1	-	6	0	0	2	12	2	3	14	-	1
23	0	5	17	4	0	0	-	0	-	0	-	-	0	1	-	13	49	0	23	4
24	18	31	0	-	4	-	3	7	8	33	0	31	0	0	23	16	0	0	-	41
25	11	7	14	5	1	2	1	13	3	19	11	26	0	4	3	1	9	12	-	4
26	67	0	4	0	7	-	23	1	-	6	1	-	2	0	0	3	2	3	26	-
*27	0	-	33	-	-	44	-	-	-	-	-	-	-	44	-	36	-	-	-	30
28	2	1	7	1	5	0	11	8	1	7	0	0	0	0	11	6	13	4	-	1
29	0	0	0	0	0	-	-	5	1	0	0	0	0	0	1	0	12	-	16	0
*30	-	13	5	11	-	-	20	6	13	27	-	-	16	5	6	5	14	3	0	8
31	2	0	0	1	2	-	1	1	-	0	0	0	-	14	12	2	-	-	-	1
*32	-	9	-	3	-	-	13	8	6	30	-	-	13	3	2	8	10	6	-	12
33	-	13	-	-	1	15	0	-	13	1	2	12	-	-	1	3	-	-	0	13

(*) - Detection Task
(-) - Either an error was made in responding or no response was made.

TABLE V

Reaction Times in Seconds - Run 3

SUBJECT

ACTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
*1	3	4	5	1	0	4	4	5	3	4	5	3	3	5	7	5	5	3	3	5
*2	5	4	4	3	4	3	4	4	9	5	6	3	4	4	6	4	5	4	3	5
*3	2	2	3	1	3	2	13	4	3	4	4	3	3	1	3	2	4	3	2	5
4	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	17	0	1
*5	4	3	5	3	4	3	4	5	5	5	9	3	3	6	8	5	5	3	5	6
6	5	1	4	3	1	1	0	2	2	2	1	3	0	2	3	3	4	3	0	2
7	2	1	4	2	1	0	2	3	2	1	0	2	0	1	2	2	2	1	0	2
*8	3	4	3	4	4	5	3	3	4	6	5	3	3	4	11	4	10	3	2	5
*9	8	8	7	5	8	7	5	5	6	8	14	18	5	6	-	6	6	6	4	7
*10	4	4	6	3	6	2	4	5	5	5	5	6	5	7	7	4	5	3	2	6
11	14	14	4	2	1	0	5	11	3	19	2	3	0	1	13	0	11	13	0	3
12	6	1	6	5	13	2	2	2	-	2	13	10	0	-	5	4	4	25	3	7
*13	5	8	4	3	9	2	8	14	5	6	3	4	8	14	4	5	5	3	3	9
14	-	0	17	3	0	0	14	0	-	0	1	5	0	0	2	6	2	3	0	0
15	4	1	-	19	4	0	7	2	44	59	4	38	0	6	5	-	4	2	0	4
16	4	8	4	13	1	5	14	5	4	8	18	1	3	6	6	2	10	3	0	4
17	6	0	-	5	3	0	4	8	7	51	6	5	0	1	7	3	2	4	0	6
18	2	0	8	0	0	0	0	0	2	5	6	0	0	0	3	0	3	1	0	0
*19	5	3	2	3	3	15	4	14	14	17	5	5	4	2	8	4	12	3	3	4
*20	13	3	17	3	3	7	2	4	4	17	9	64	2	2	5	1	17	12	1	3
21	9	2	36	19	8	2	13	26	8	-	7	31	6	4	18	2	10	-	0	8
22	0	0	0	0	0	0	14	2	0	19	0	0	0	0	24	0	5	0	0	2
23	7	4	4	11	3	2	14	2	3	15	10	63	5	7	35	14	4	12	0	5
24	0	25	28	0	0	0	4	-	0	0	6	29	0	-	38	1	0	-	0	0
*25	5	35	-	3	18	1	-	2	4	38	43	-	3	16	20	12	23	21	-	6
26	34	1	3	-	0	11	4	12	42	4	3	10	17	29	43	-	5	2	0	-
27	9	11	3	3	14	-	5	12	3	-	4	26	15	16	4	1	3	-	0	4
28	3	20	-	4	0	-	-	35	13	0	27	-	1	-	5	2	28	1	-	-
29	23	0	-	-	1	0	6	0	35	0	10	0	8	9	50	-	8	2	-	14
30	9	0	0	-	0	0	0	7	0	-	0	0	4	0	27	0	0	0	-	0
*31	18	11	7	20	32	-	-	7	24	-	-	-	6	15	27	5	20	22	1	14
*32	-	24	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
33	2	0	-	0	1	0	0	15	6	9	2	0	0	2	35	22	0	0	-	1
*34	12	-	-	-	4	12	-	-	19	9	6	12	4	6	-	-	5	14	9	6
*35	9	-	-	9	10	-	3	6	-	-	3	11	3	9	-	-	-	7	-	4

(*) - Detection Task
(-) - Either an error was made in responding or no response was made.

TABLE VI

Reaction Times in Seconds - Run 4

SUBJECT

ACTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
*1	3	5	4	3	3	4	3	3	5	4	5	4	6	4	7	4	3	4	3	5
*2	3	4	5	4	4	4	3	4	5	3	5	3	4	5	7	3	5	3	4	4
3	4	1	3	3	1	4	2	1	3	1	4	1	1	5	3	1	4	4	3	3
*4	4	3	4	3	4	4	3	5	3	6	3	3	6	4	5	2	4	3	2	4
*5	4	3	4	3	4	4	3	4	3	5	5	3	4	6	5	2	3	3	3	5
*6	2	2	2	3	4	4	3	2	2	2	2	3	3	2	5	5	3	3	3	2
7	6	1	1	3	1	1	1	1	2	0	1	1	1	1	7	1	3	4	1	2
8	0	0	0	0	0	2	0	0	0	0	0	0	0	0	5	0	7	3	9	0
*9	3	2	2	3	3	12	3	3	3	2	7	3	4	7	5	2	4	5	2	3
10	5	1	3	4	2	4	1	2	3	1	3	1	2	4	4	4	3	4	2	5
*11	12	3	3	3	4	3	3	3	4	4	3	5	3	5	5	4	4	3	7	4
12	4	1	0	0	3	3	3	3	2	2	3	1	0	2	0	3	3	6	2	1
13	7	6	1	0	8	4	6	4	6	6	6	3	0	2	-	6	6	8	7	5
14	4	0	2	2	3	-	24	2	0	4	2	3	1	5	-	2	0	2	1	3
*15	6	3	11	4	5	5	4	4	6	6	5	6	6	10	7	4	6	4	5	6
16	5	1	4	3	1	1	3	2	3	32	2	1	0	27	10	17	4	-	1	4
*17	6	6	36	4	11	6	24	16	6	3	16	17	4	7	3	4	12	3	4	11
18	12	2	11	4	13	3	-	5	14	0	3	1	2	8	6	12	21	-	2	10
19	0	0	0	0	0	1	0	0	0	23	0	5	0	-	0	0	0	-	5	15
*20	6	11	-	3	7	8	6	16	7	38	25	21	3	7	11	9	23	12	16	4
21	34	0	31	4	1	0	0	1	4	-	2	1	0	6	47	3	3	5	7	0
22	2	3	15	-	3	4	-	3	0	36	27	15	-	0	53	21	12	2	14	4
*23	3	3	-	3	13	8	14	9	33	2	6	62	2	18	5	15	30	7	14	2
24	6	0	0	0	4	3	3	0	3	0	3	0	0	0	0	3	1	3	3	2
25	11	0	0	0	7	6	5	0	6	0	5	0	0	9	2	8	3	3	6	5
*26	9	10	13	5	8	6	14	27	22	2	26	27	11	33	19	14	23	2	7	13
27	51	36	-	16	4	-	15	78	85	91	42	99	4	8	15	-	10	-	-	5
28	22	0	2	13	1	12	2	2	2	0	7	1	0	21	6	15	-	-	0	2
29	27	9	0	-	0	-	5	4	3	0	7	2	0	13	12	0	0	3	1	0
30	13	7	5	3	3	-	2	2	2	0	12	2	0	71	-	0	21	12	55	10
31	0	0	-	6	-	5	0	0	0	0	0	0	-	-	4	-	1	22	0	4
*32	5	16	-	9	20	18	63	99	43	-	3	65	12	28	7	1	19	2	13	15
33	9	0	2	-	-	-	12	0	12	0	2	0	0	1	35	0	5	6	0	42
*34	23	2	-	4	6	-	77	13	-	2	34	-	32	-	96	6	1	3	4	3
35	0	0	0	0	0	2	0	4	20	0	1	0	0	-	6	3	5	4	14	-
36	12	3	-	10	11	4	-	9	-	-	4	-	7	-	-	11	0	5	-	3
*37	50	5	-	7	8	-	-	51	-	11	27	13	27	-	-	5	13	12	-	28
38	0	12	0	5	8	1	13	0	1	0	4	13	0	3	0	9	8	13	4	3
39	2	16	2	6	11	3	14	0	3	0	4	15	2	39	-	6	11	15	1	6
40	-	7	-	-	-	14	3	4	-	0	38	7	8	0	-	-	-	-	7	9
41	-	-	-	0	-	12	-	-	-	-	-	-	2	0	7	-	4	-	27	7
*42	16	-	-	-	8	2	-	13	-	-	-	-	-	-	-	-	-	-	-	-

TABLE VII

Times At Which Errors Were Made (Run 2)

	OPERATOR																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TIMES OF ERRORS	582	533	582	482	533	372	451	500	482	471	406	473	311	592	334	393	533	338	114	331
	582		591	533	582	442	463	533	533	512	499	482	331		483	413	583	393	334	335
	591			591	582	482	482	591	533	533	533	499	340		533		592	443	364	477
					597	512	533	597	582		582	512	533					533	442	
						542	552				582	533	543					553	470	
						552	573					582	578					583	471	
						582						582	582					592	473	
						582						595	591					596	483	
						582													511	
						585													521	
						600													525	
																			533	
																			583	
																			583	

NOTE: The times given are the number of seconds after the simulation run began.

TABLE VIII

Times At Which Errors Were Made (Run 3)

	OPERATOR																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TIMES OF ERRORS	344	582	382	522	571	531	366	418	348	472	563	522	571	332	283	382	571	472	522	522
	571	592	393	533		533	522	474	375	531	571	533	600	512	547	522	592	512	532	533
			522	550		563	533	512	571	558		563		533	571	533	597	531	535	544
			533	558		571	563	571	592	563		571		571	582	571		571	540	571
			533	571		592	581	582		571					592	582		593	558	
			571	582			592	604		592						592			560	
			571													602			571	
			582																588	
			592																592	

NOTE: The times given are the number of seconds after the simulation run began.

TABLE IX

Times At Which Errors Were Made (Run 4)

	OPERATOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TIMES OF ERRORS	269	522	366	383	473	293	342	522	503	381	502	503	342	352	272	433	433	331	433	521
	522	573	393	471	492	433	383	573	522	483	573	522	383	482	293	482	552	342	523	522
	575	583	433	492	522	471	397		523	522	575	523	440	503	473	522	583	352	542	583
	589	586	473	522	552	473	522		530	523	583	570	473	521	522	552		433	583	
	596		483	552	573	492	525		542	573		573	522	522	523	573		433		
			503	583	575	503	542		552	573		583	583	523	542	583		522		
			522			522	549		560	583		600		542	552			552		
			523			542	573		573						552			573		
			542				583		578						583			574		
			552						583						592			583		
			573															590		
			593																	

NOTE: The times given are the number of seconds after the simulation run began.

VITA

Dahl B. Metters was born [redacted], after graduating from [redacted], he attended Bemidji State College in Bemidji, Minnesota, for two years and then graduated from the University of Minnesota in 1963.

He entered Officer Training School and was commissioned in 1963. After numerous assignments as a Ground Electronics Officer, he was selected for the undergraduate Electrical Engineering program at the Air Force Institute of Technology. After receiving a Bachelor of Science degree in June 1974, he continued on in the graduate program in Electrical Engineering.

In 1974, he was nominated for membership in Who's Who Among Students in American Universities and Colleges, and was selected to receive the Air Force Institute of Technology's Mervin E. Gross award. He is a member of the Institute of Electrical and Electronics Engineers, Tau Beta Pi, and Eta Kappa Nu.

Permanent Address: c/[redacted]

PII Redacted